BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Verification of the Existence of the 1978 Triple-Planet Flyby Opportunity - Case 720

DATE: October 19, 1967

FROM: A. A. VanderVeen

ABSTRACT

A third category of triple-planet ballistic flyby opportunities was found in late 1978. A typical trajectory is tabulated, and its general characteristics are discussed.

Some observations regarding triple-planet flybys, dual-planet flybys, and Venus swingby trajectories are presented.

(NASA-CR-90669) VERIFICATION OF THE EXISTENCE OF THE 1978 TRIPLE-PLANET FLYBY OPPORTUNITY - CASE 720 (Bellcomm, Inc.) 13 p

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MEMORANDUM FOR FILE

General

A triple-planet (Earth-Venus-Mars-Venus-Earth) ballistic flyby launch opportunity was recently found to exist in mid-1981[1]. Since it was comprised of a different combination of Venus swingby trajectories than the 1977 triple-planet flyby opportunity[2], it was speculated that a third combination of swingby trajectories might yield another triple-planet flyby in late 1978. This flyby opportunity was indeed found. Table I lists one of its typical trajectories, and its mission profile is shown in Figure 1. It is noted that this opportunity is essentially the 1978 dual-planet flyby with its return leg modified to pass Venus, thereby extending its trip time to about 800 days.

TABLE I

EVENT	DATE		V_∞	PASS RAD.	PERI VEL.	INJ/ENTRY VEL.
	(Julian)	(Calendar)	(Emos)	(P.R.)	(FPS)	(FPS)
Earth Dep.	244 3840	28 Nov 78	0.1722			14,300
Venus Pass	244 4004	11 May 79	0.3444	1.289	44,900	
Mars Pass	244 4202	25 Nov 79	0.1636	2.370	19,300	
Venus Pass	244 4419	29 Jan 80	0.2186	1.316	36,300	
Earth Arr.	244 4635	31 Jan 81	0.2384			43,000

Cursory examination of the trajectory data associated with this flyby opportunity shows that the launch window begins with the tabulated trajectory and extends to J. D. 244 3875, after which the earth departure V-infinity vector becomes greater than 0.25 emos*. Earth arrivals earlier than J. D. 244 4630 impact Venus at its second encounter regardless of the launch date. Hence, a thirty-five day launch window exists and trip durations range from 760 to 800 days. The injection velocity is noted to be small during the early part of the window, and the earth-entry velocity is low. The passage velocities at Mars and Venus' second encounter are quite slow, which is important from the standpoint of observation time within the planets' sphere of influence, probe deployment and control, and probe design requirements.

Planetary Encounter Characteristics

The first Venus passage occurs with the periapsis position in the sunlit side about forty-five degrees after the sub-solar point and about eight degrees above the equator on an azimuth of ninety degrees. (Figure 2) The passage velocity is about 45,000 fps at an altitude of 960 nm.

The flyby characteristics of the Mars encounter are attractive in certain respects and less attractive in others. The passage velocity is low, but periapsis occurs well into the darkside at a northern latitude of 24 degrees. (Figure 3) The heading there is west-northwest. The approach-target point and the exit-point each lie near opposite terminators, so the full darkside is traversed during the passage. Radar and infra-red mapping of the surface would have to supplement conventional photographic mapping.

The second Venus encounter has entirely different characteristics from the first. (Figure 4) The flyby inclination is 140 degrees, which means that the passage is between polar and retrograde. Periapsis occurs approaching the darkside on the terminator at a southern latitude of 24 degrees on a northwesterly azimuth. The approach-target point lies within 40 degrees of the sub-solar point.

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*1 emos = 97,702 ft/sec. The earth-mean-orbital-speed is the normalizing factor applied to V-infinity vector magnitudes.

Depending upon the nature and purpose of experiments and probes carried, the very diverse flyby characteristics associated with the separate encounters may prove to be an attractive feature of this mission opportunity.

Clarification of the Type Classification

It is worth clarifying the "Type" classification that was established (somewhat arbitrarily) by Gillespie and Ross[3] in regard to Venus swingby trajectories, so that the pattern of triple planet flyby opportunities may be explained more easily.

The Venus swingby trajectories can be related in some manner to the Mars-Venus alignment date occurring within the time frame of the mission opportunity. Gillespie and Ross designated both outbound and inbound swingbys by types numbered from one through seven according to Table II. On the basic of Mars stopover missions the Venus swingby types were evaluated in competition with direct-leg trips. The even numbered types were immediately discarded as unusable because Venus is not in a favorable position to match a reasonable direct leg with a swingby leg on a roundtrip mission. The number sevens were rejected by virtue of being non-competitive on the basis of extended trip time, since a direct leg is always available during the same time period. The number one types were generally found to impact Venus, and hence, were relegated to a state of marginal usefulness. The number threes were always found to be advantageous over direct trips at the cost of longer trip durations, and the number fives -- occurring in pairs (outbound-inbound) -- were attractive for short stopover times.

The Triple-Planet-Flybys

The 1977 triple-planet flybys were found by adjusting the dates associated with the pair of number five swingbys so that the hyperbolic excess velocities at Mars matched on arrival and departure, while also passing above the planet's surface. The symmetry associated with the planetary positions at their encounter dates suggested a uniqueness that would not be repeated again until a 6.4 year period had elapsed. (In fact, data generated for a similar mission in 1983 verifies that the mission characteristics are repeated with only nominal differences.)

TABLE II*

Mars-Venus Alignment Cal. Date	J. Date	Heliocentric Longitude	Venus Swingby Type # Outbound	Inbound
14.6 Oct 75	2442700.1	49.97°	7	2
25.7 Aug 76	2443016.2	197.90°	6	3
11.6 Aug 77	2443367.1	38.68°	5	4
25.7 Jun 78	2443685.2	189.71°	4	5
9.3 Jun 78	2444033.8	26.79°	3	6
24.9 Apr 80	2444354.4	181.71°	2	7
5.6 Apr 81	2444700.1	14.32°	1	1
23.1 Feb 82	2445023.6	173.84°	7	2
31.5 Jan 83	2445366.0	1.32°	6	3
24.4 Dec 83	2445692.9	166.08°	5	4
27.2 Nov 84	2446031.7	347.93°	4	5
23.8 Oct 85	2446362.3	158.37°	3	6
23.7 Sep 86	2446697.2	334.33°	2	7
24.1 Aug 87	2447031.6	150.68°	1	1
20.2 Jul 88	2447362.7	320.72°	7	2
23.5 Jun 89	2447701.0	142.97°	6	3
16.9 May 90	2448028.4	307.33°	5	4
23.8 Apr 91	2448370.3	135.19°	4	5
12.8 Mar 92	2448694.3	294.34°	3	6
21.1 Feb 93	2449039.6	127.31°	2	7
8.0 Jan 94	2449360.5	281.87°	1	1
22.2 Dec 94	2449708.7	119.28°	7	2
5.6 Nov 95	2450027.1	270.00°	6	3
21.3 Oct 96	2450377.8	111.06°	5	4
2.6 Sep 97	2450694.1	258.73°	4	5
21.2 Aug 98	2451046.7	102.60°	3	6
1.9 Jul 99	2451361.4	248.05°	2	7

The 1981 triple-planet flyby was discovered somewhat by accident during the analysis of a Mars-Venus dual-planet flyby in which the Earth-Mars leg circumscribed the sun at length in the vicinity of Venus' orbit. Venus was determined to be in the vicinity at the right time. When the successful triple flyby was found, it was determined to be comprised of a type number seven outbound matched with a number three inbound type. Since a number seven type was involved, its rejection as a usable swingby type was immediately questioned.

*Contents taken with permission from Reference 4.

What was overlooked heretofore was the fact that Venus swingby trips have been viewed in competition with opposition class (direct) trips with the Venus encounter serving primarily to alter some unfavorable mission characteristics, whereas the primary purpose of the planetary encounter may be the encounter itself; and while the swingby opportunities serve as a guide for locating flyby opportunities, assumptions based on one class of trip do not necessarily apply to the other.

General Observations

Examination of Table II shows that the sequence of triple-planet flybys are comprised of type combinations: #7/#3, #5/#5, #3/#7,.....,with time intervals of 1.83, 1.83, 2.74,.....,(years).

It is observed that when the Venus passage is associated with a number three type swingby, the passage velocities are high, whereas the number fives pass somewhat more slowly and the number sevens pass Venus at low velocity. This phenomena is due to the angular relationship existing between the spacecraft's trajectory and Venus' orbit at the time of encounter. The number threes cross Venus' orbit at an appreciable angle as a result of the spacecraft's excursion around the sun at less than 0.6 a.u. (generally), while the number sevens appear to encounter Venus' orbit tangentially. The number fives encounter Venus at a slight angle, which produces a moderate passage velocity.

It should not be construed to mean that, because the additional types of triple-planet flyby opportunities have been found, three times as many multi-planet flyby opportunities exist. In each case the triple flyby has been found to be a special case of a dual flyby, just as the Venus swingby mission can be considered a special case of the opposition class mission. However, just as some opposition trips are unfavorable and some of the recognized swingby trips are quite long, some dual-planet flybys are unattractive and most triple-planet flybys are long.

The triples make two notable contributions to the family of Mars-Venus multi-planet flyby opportunities: They provide an additional launch opportunity when they occur in the same general time period as a Mars-Venus sequence dual-planet flyby, i.e., inbound swingby (because the outbound leg is modified significantly); and they provide the feature of having an "optional return capability" utilizing the direct leg to earth, when the associated dual-planet has a Venus-Mars encounter sequence, i.e., outbound swingby.

Conclusions

Three different categories of triple-planet ballistic flybys have been identified, and their general characteristics have been found to relate to the Venus swingby trajectories, of which they are comprised. Since each involves either a type five or a type seven, at least one slow passage of Venus will be available during each opportunity -- an important consideration regarding probe design.

The triple-planet flybys are special cases of dual-planet flybys, in which the Earth-Mars leg is modified to fly by Venus.

The option is available to exclude the second Venus passage and return to earth nine months earlier.

An adequate launch window exists for all three categories of triple-planet flyby opportunities accompanied by "easy" injection conditions. The trip durations are quite long.

A. A. VanderVeen

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Attachments
References
Figures

References

1. Bankovskis, J. B., and VanderVeen, A. A., "The Existence of a 1981 Triple-Planet Ballistic Flyby," Bellcomm Memorandum for File dated September 19, 1967.

2. VanderVeen, A. A., "Families of 1977 Triple-Planet Flybys," Bellcomm Memorandum for File dated June 6, 1967.

3. Gillespie, R. W., and Ross, S., "The Venus Swingby Mission Mode and Its Role in the Manned Exploration of Mars," AIAA Third Aerospace Sciences Meeting, Paper No. 66-37, 1966.

4. Space Flight Handbook, Vol. 3 - Planetary Flight Handbook, Part 6, (To be published) NASA SP-35, 1967.

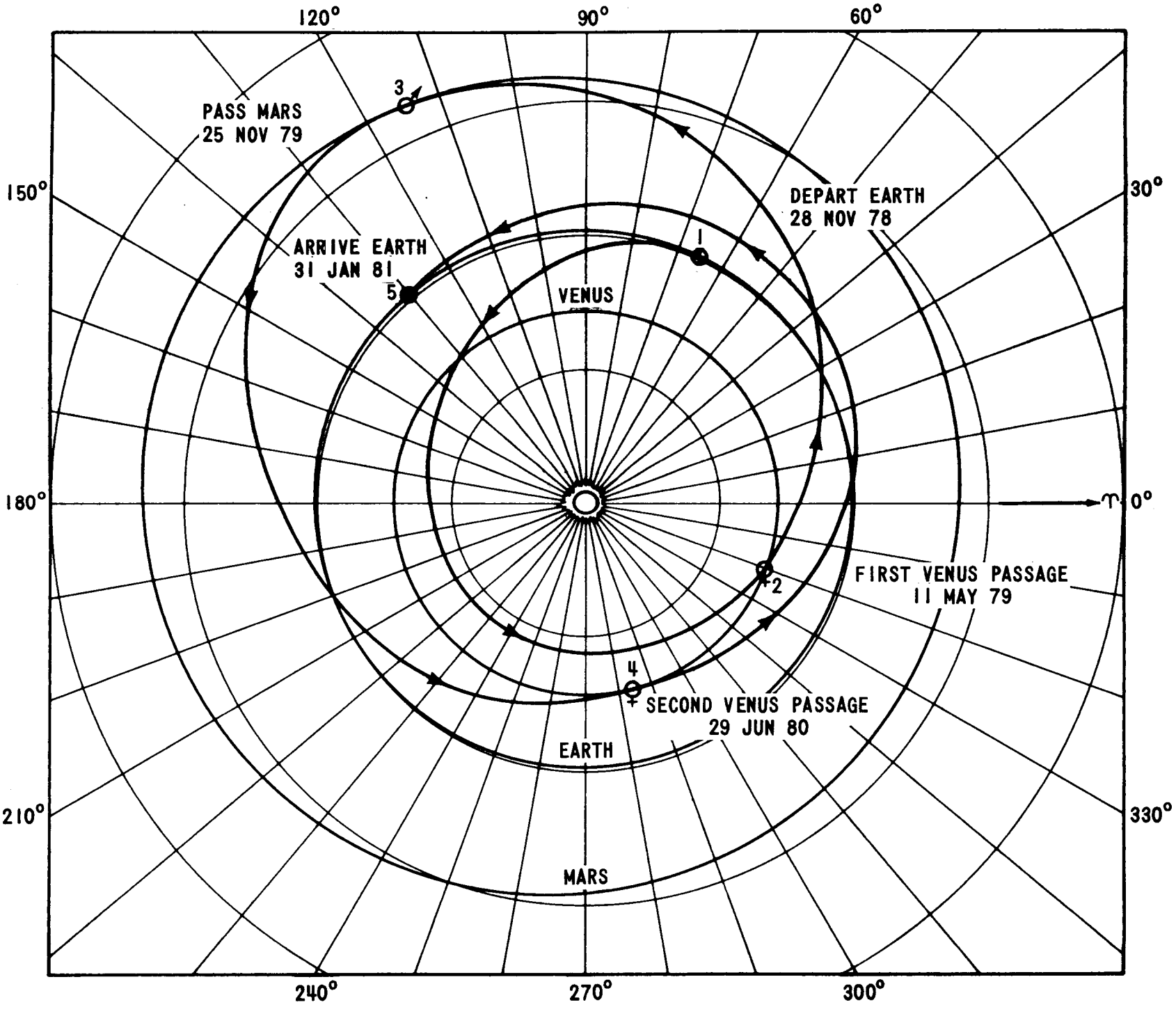

FIGURE 1 - MISSION PROFILE - 1978 TRIPLE-PLANET FLYBY

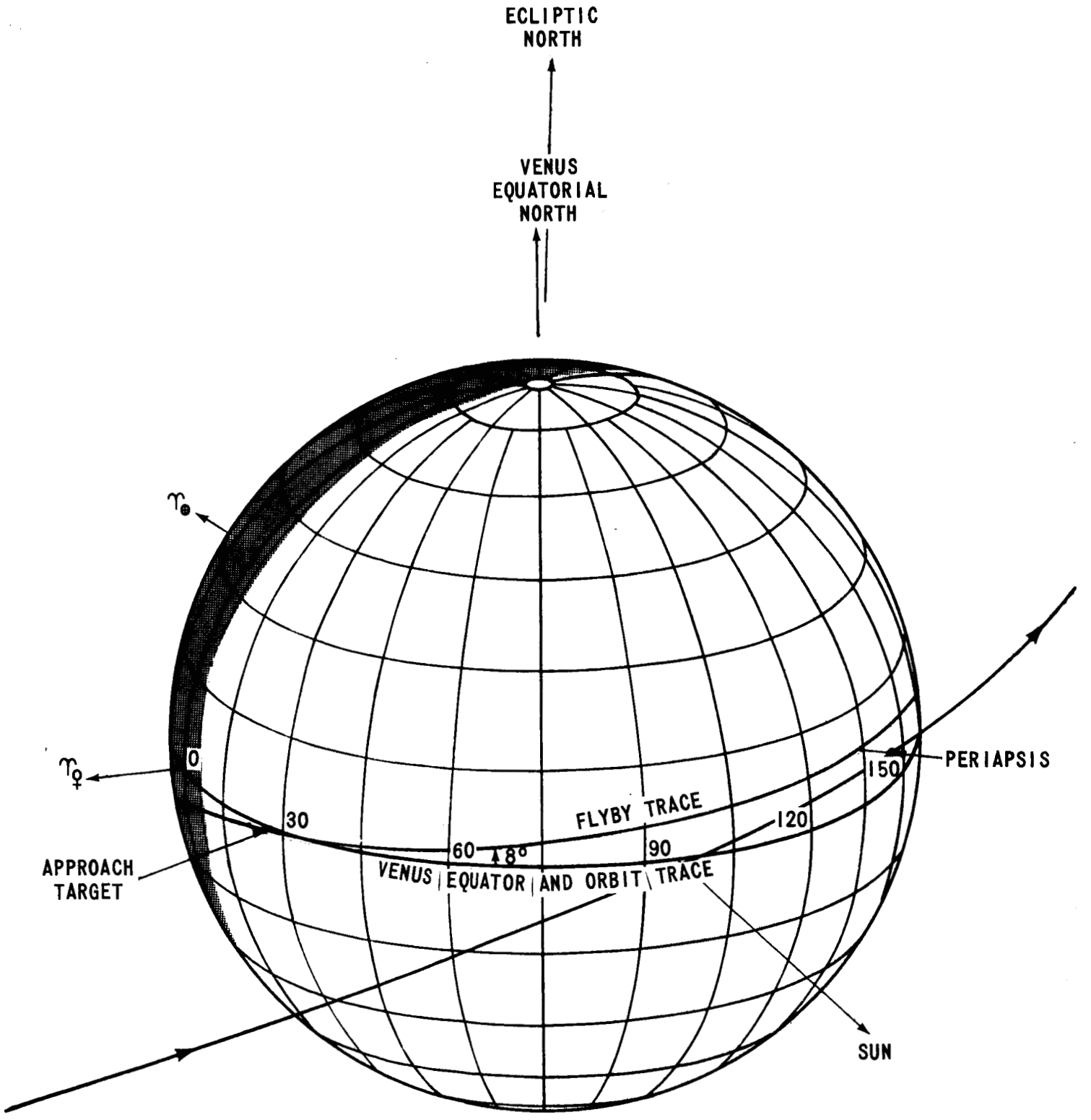

FIGURE 2 - FIRST VENUS PASSAGE - 1978 TRIPLE-PLANET FLYBY

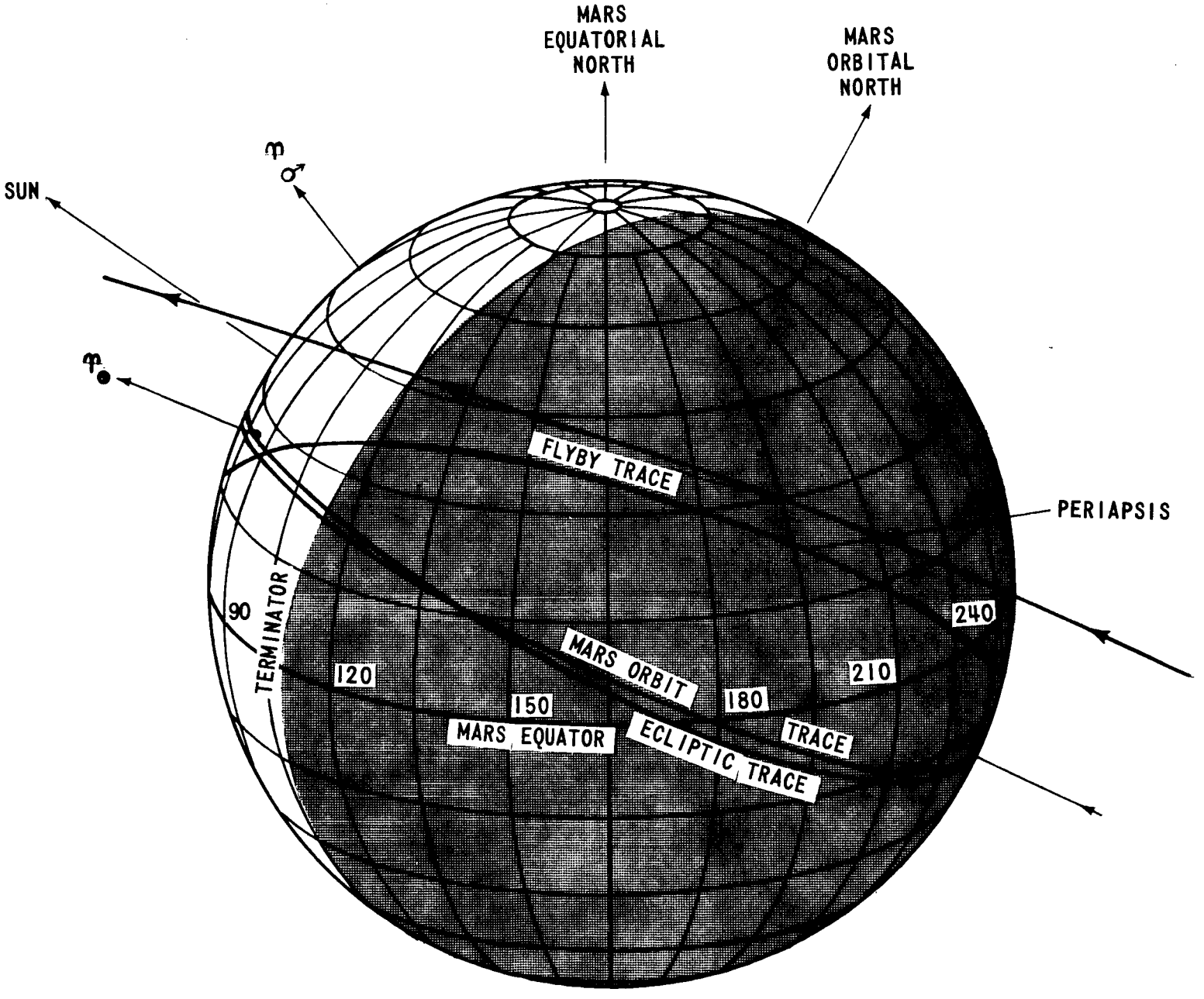

FIGURE 3 - MARS PASSAGE - 1978 TRIPLE-PLANET FLYBY

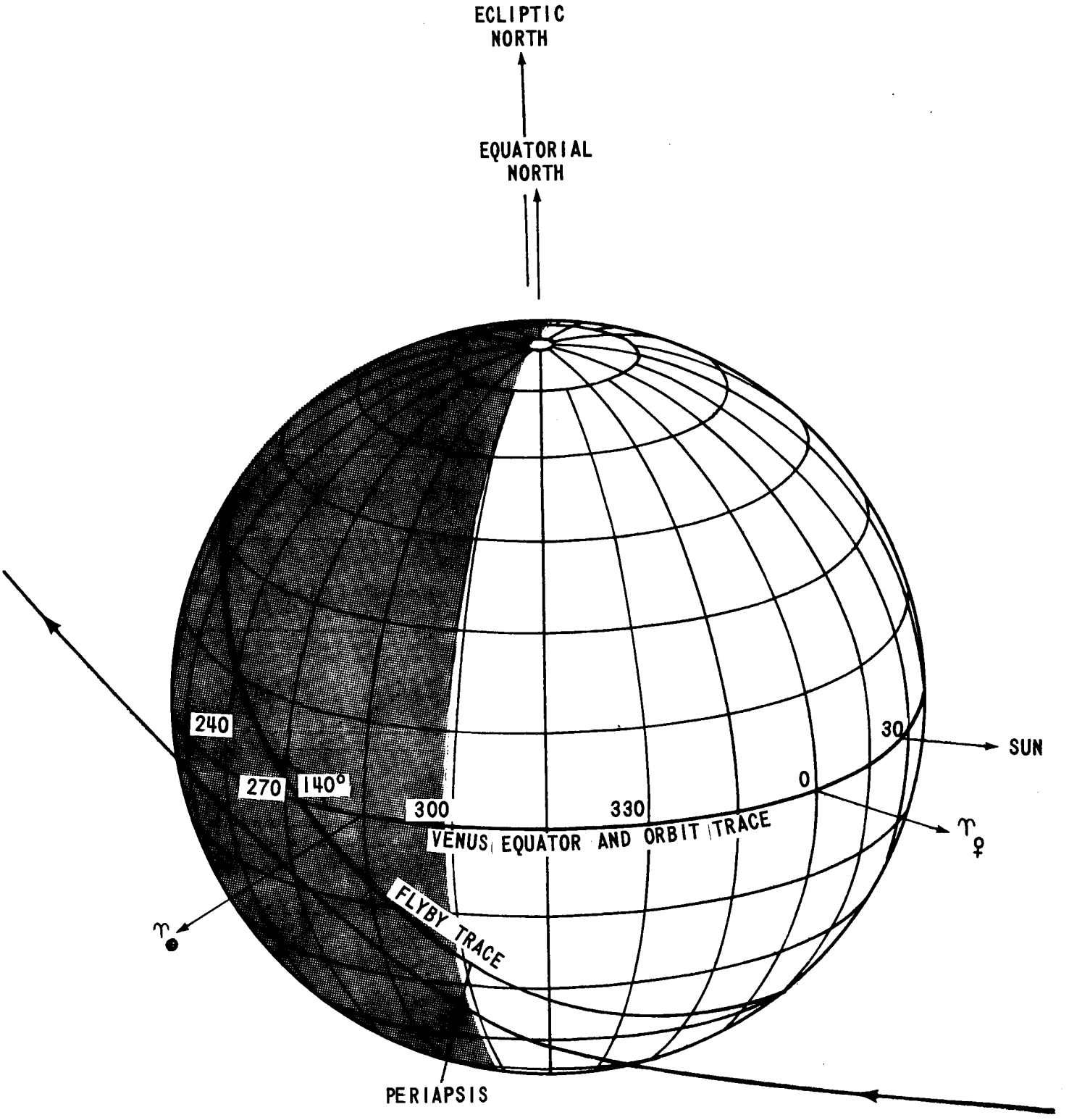

FIGURE 4 - SECOND VENUS PASSAGE - 1978-PLANET FLYBY

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